Fig.1

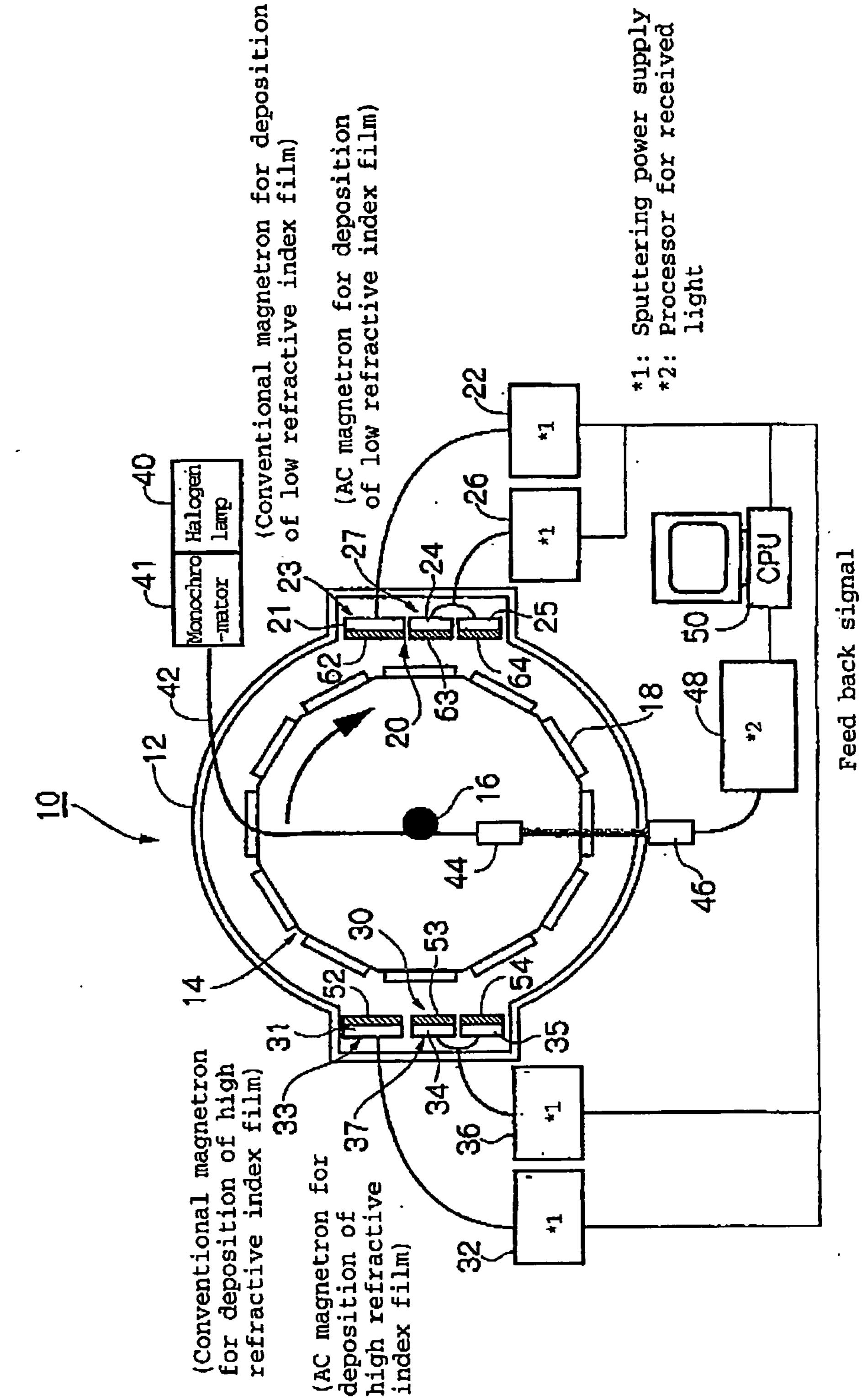
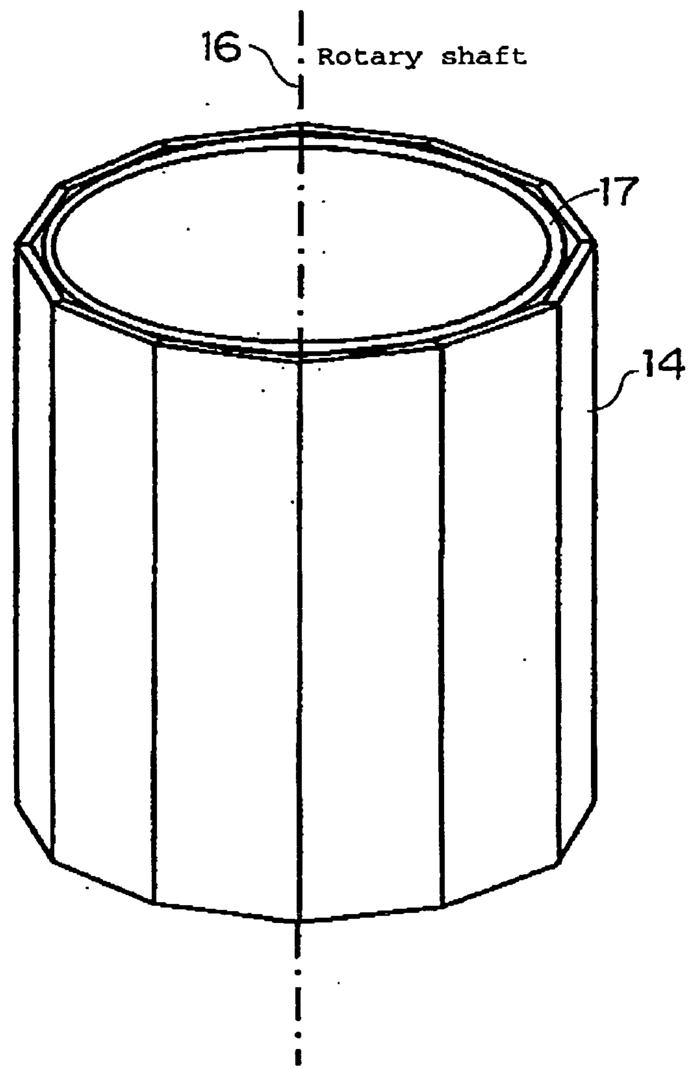
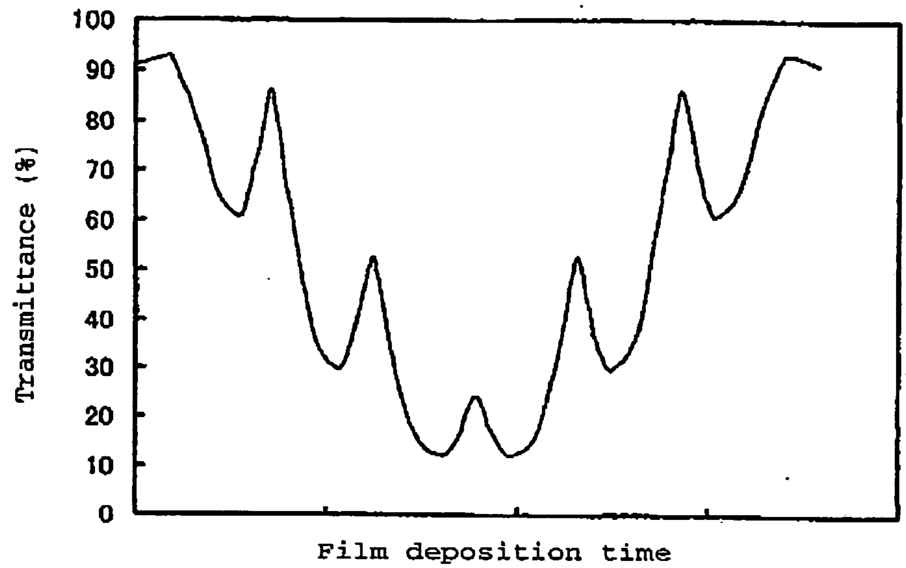

10
12
14
16
18
20
21
22
23
24
25
26
27
30
31
32
33
34
35
36
37
40
41
42
44
46
48
50
52
53
54
62
63
64
Halogen lamp
Monochro-mator
CPU
*1
*2
Feed back signal
(Conventional magnetron for deposition of low refractive index film)
(AC magnetron for deposition of low refractive index film)
(Conventional magnetron for deposition of high refractive index film)
(AC magnetron for deposition of high refractive index film)
*1: Sputtering power supply
*2: Processor for received light

Fig.2



F i g. 3


100
90
80
70
60
50
40
30
20
10
0
Transmittance (%)
Film deposition time

F i g. 4

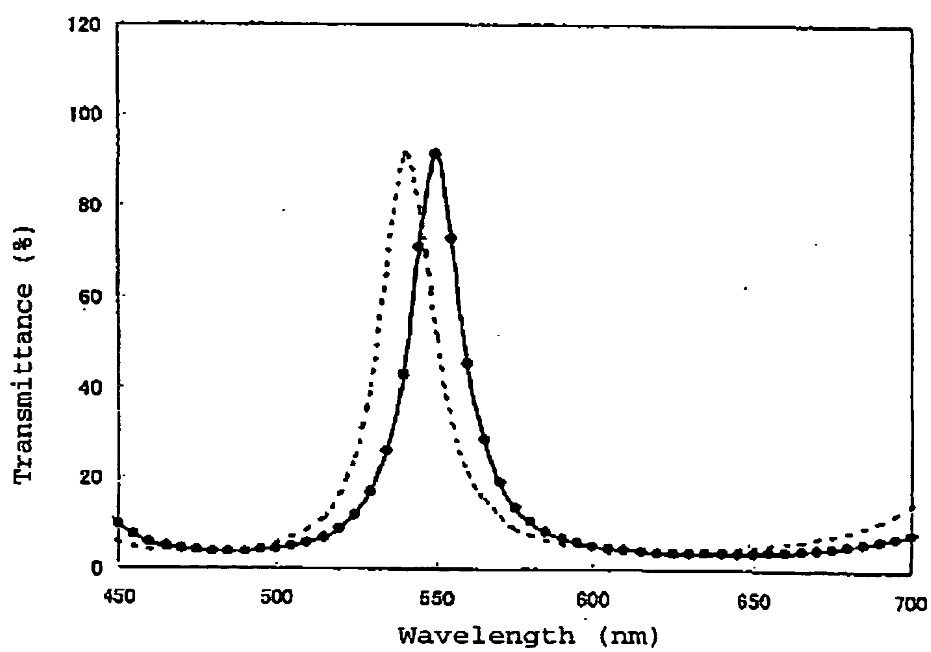

120
100
80
60
40
20
0
Transmittance (%)
450
500
550
600
650
700
Wavelength (nm)

Fig.5

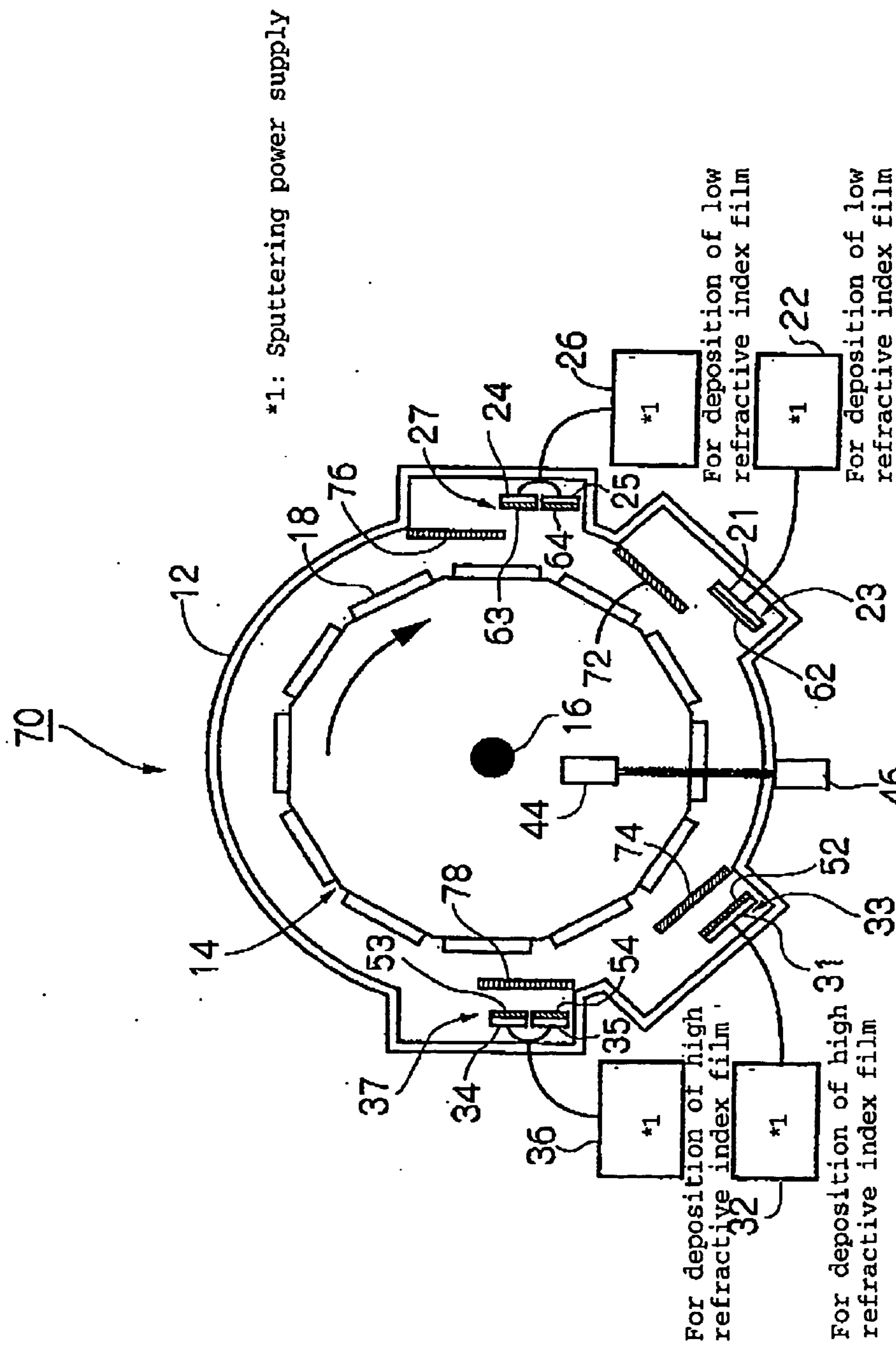
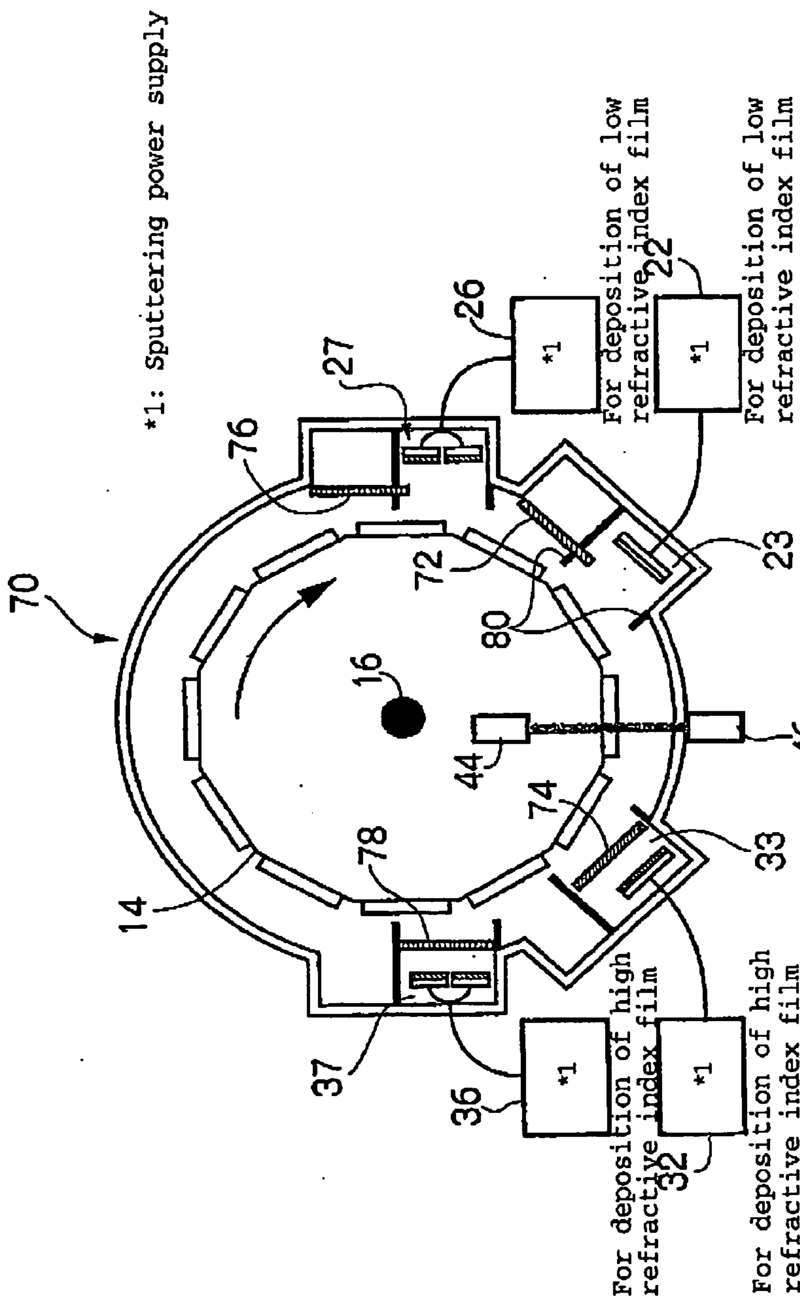
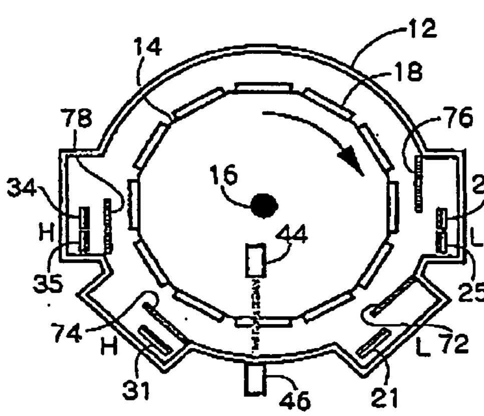

*1: Sputtering power supply
70
12
14
16
18
21
22
23
24
25
26
27
31
32
33
34
35
36
37
44
46
52
53
54
62
63
64
72
74
76
78
*1
*1
*1
*1
For deposition of low refractive index film
For deposition of low refractive index film
For deposition of high refractive index film
For deposition of high refractive index film

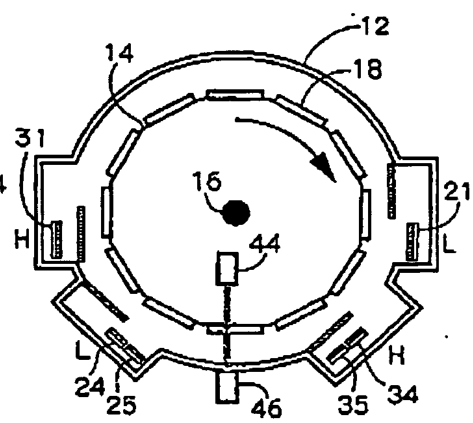
Fig.6


*1: Sputtering power supply
70
76
27
26
*1
For deposition of low refractive index film
22
*1
For deposition of low refractive index film
72
80
23
16
44
46
74
33
14
78
37
36
*1
For deposition of high refractive index film
32
*1
For deposition of high refractive index film

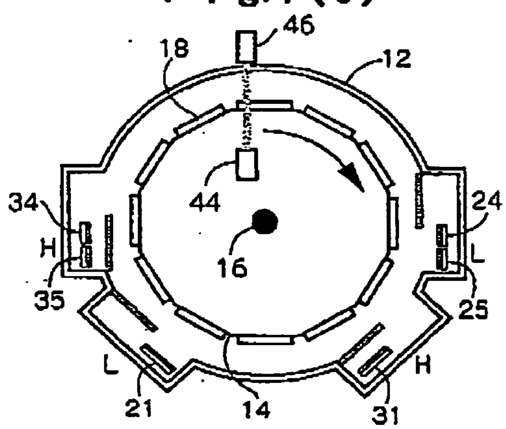
F i g.7(a)



F i g.7(b)



F i g.7(c)



F i g.7(d)

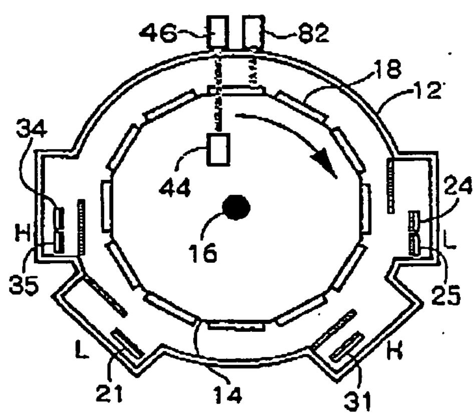


Fig. 8

	Target material	Film material
Low refractive index material	Si	SiO_2
	SiC	SiO_2
	Alloy of Si and Al	$SiO_2 + Al_2O_3$
High refractive index material	Ti	TiO_2
	Ta	Ta_2O_5
	Zr	ZrO_2
	Zn	ZnO
	Nb	Nb_2O_5

Fig. 9

Examples of substrate used in the present invention

For WDM	WMS manufactured by OHARA Corporation (glass ceramics)
For optical filter	Colorless sheet glass (high transmittance glass)
	Hard glass (low expansion glass)
	Artificial crystal
	Quartz
	BK-7 (optical glass) manufactured by Schott Corporation
	Fluorophosphate glass
	Borosilicate glass

Fig.10

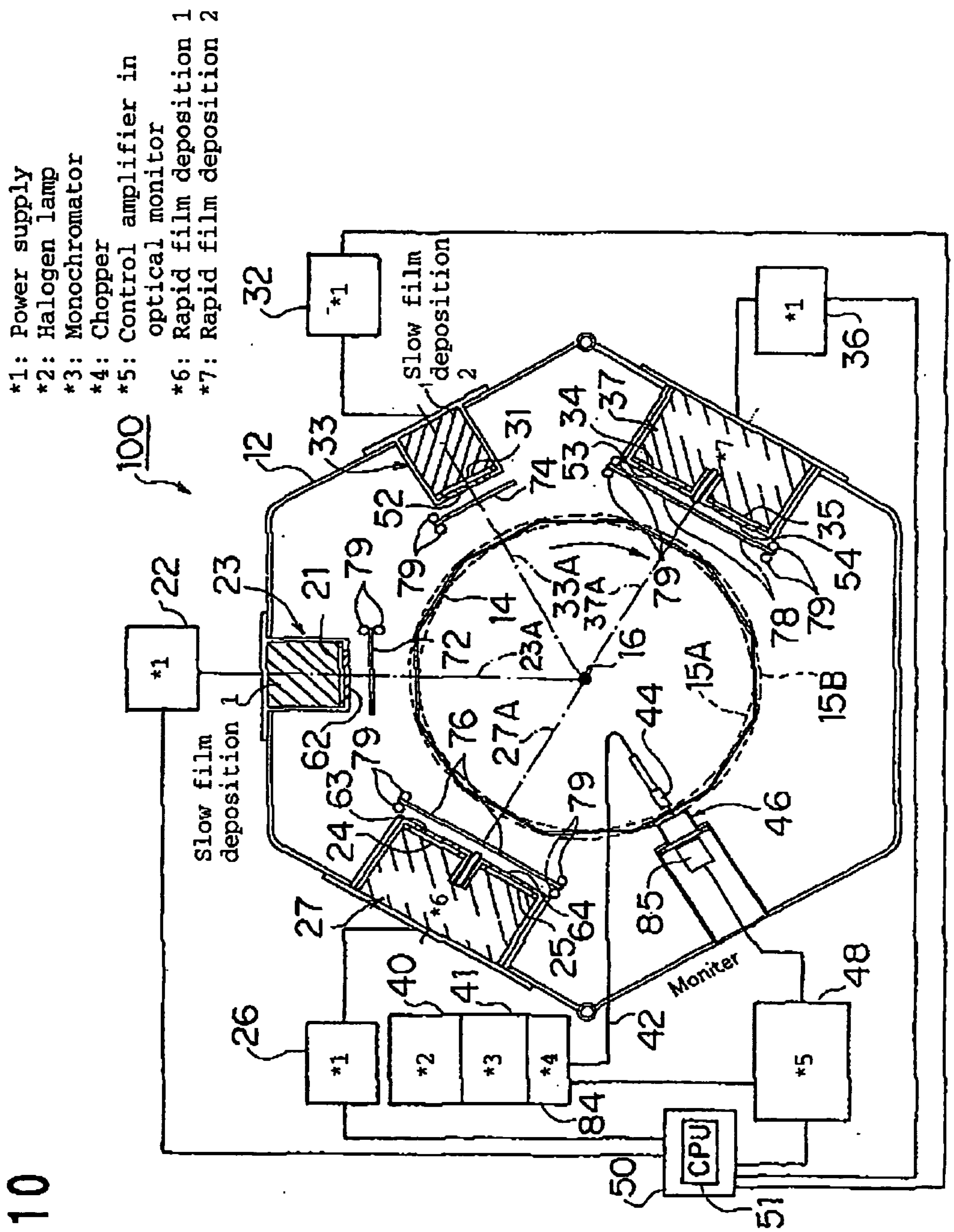
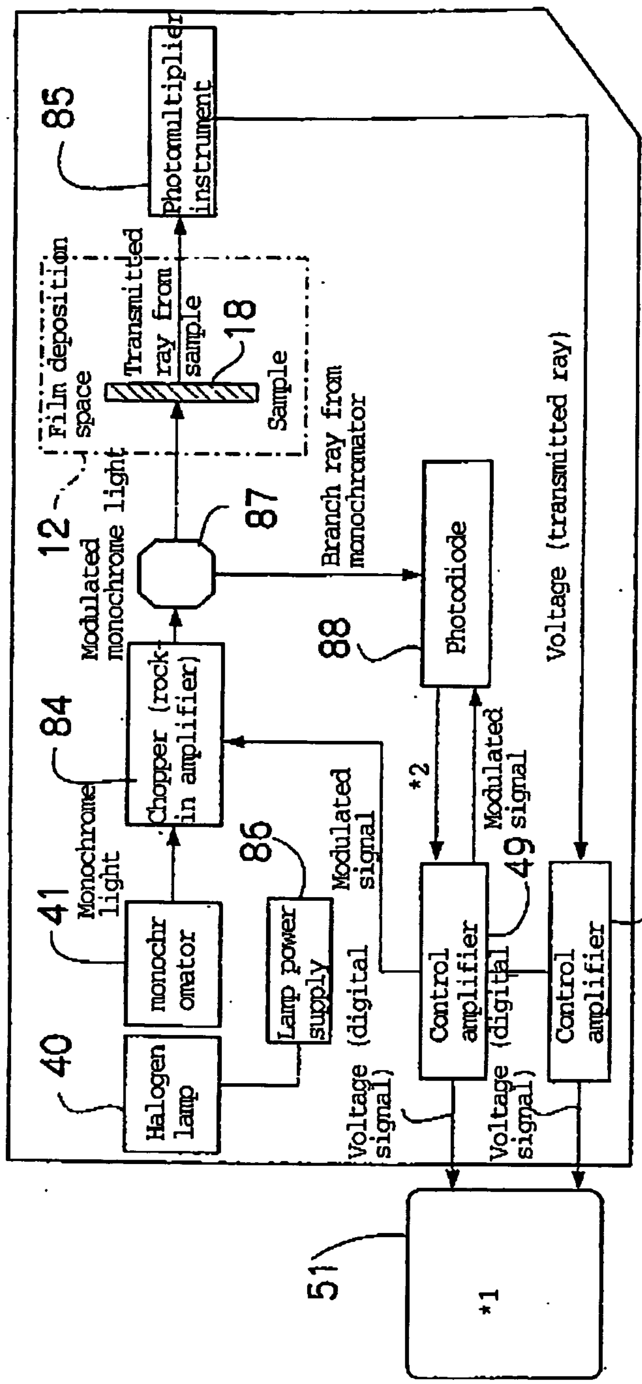

*1: Power supply
*2: Halogen lamp
*3: Monochromator
*4: Chopper
*5: Control amplifier in optical monitor
*6: Rapid film deposition 1
*7: Rapid film deposition 2
100
Slow film deposition 1
Slow film deposition 2
Moniter
CPU
*1
*2
*3
*4
*5
*6
*7
12
14
15A
15B
16
21
22
23
23A
24
25
26
27
27A
31
32
33
33A
34
35
36
37
37A
40
41
42
44
46
48
50
51
52
53
54
62
63
64
72
74
76
78
79
84
85

Fig.11



*1: CPU
(finding transmittance →
finding thickness of optical film →
finding film deposition rate

*2: Voltage (ray directly from light source)

Fig.12

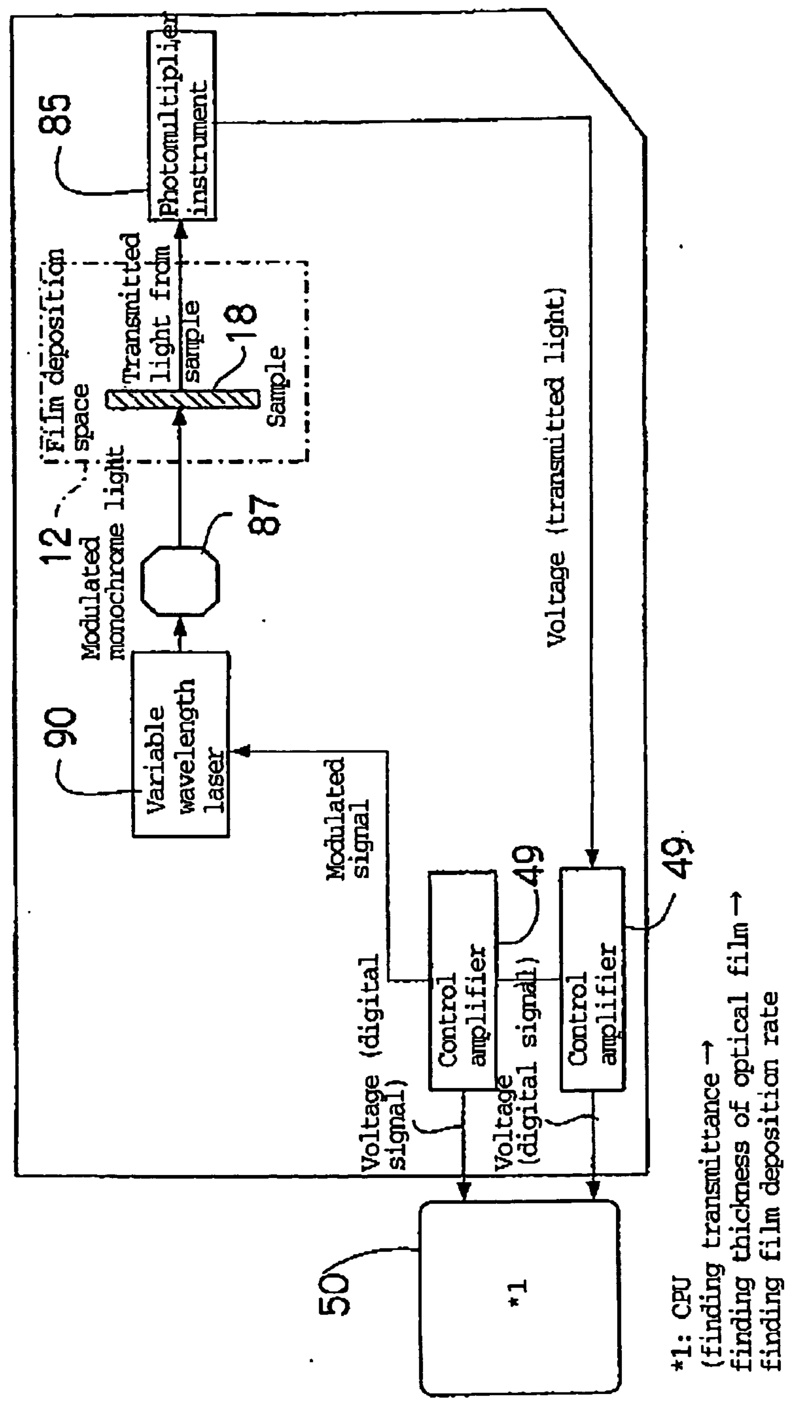

85
Photomultiplier instrument
Film deposition space
Transmitted light from sample
18
Sample
12
Modulated monochrome light
87
90
Variable wavelength laser
Modulated signal
Voltage (transmitted light)
49
Control amplifier
49
Control amplifier
Voltage (digital signal)
Voltage (digital signal)
Voltage (digital signal)
Voltage (digital signal)
50
*1
*1: CPU
(finding transmittance →
finding thickness of optical film →
finding film deposition rate

Fig.13(a)

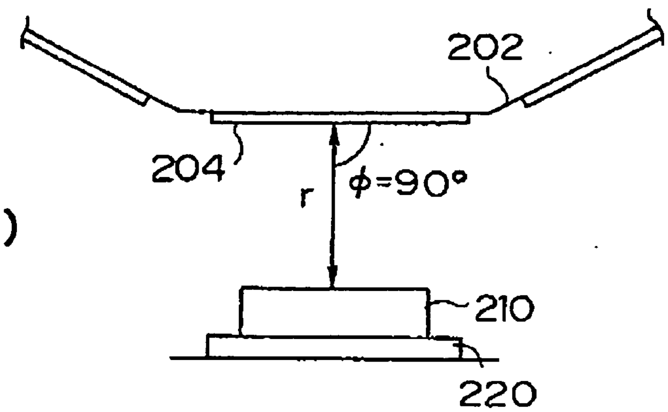


Fig.13(b)

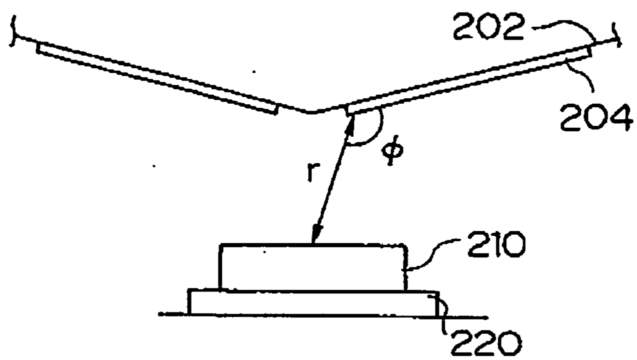
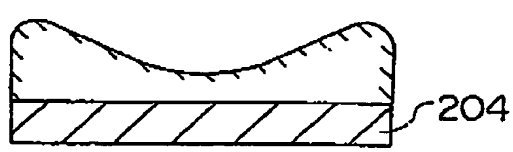


Fig.13(c)



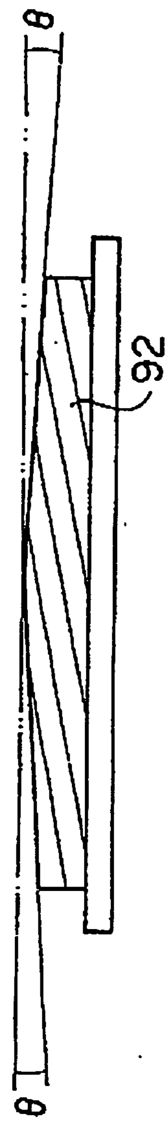


Fig.14(a)

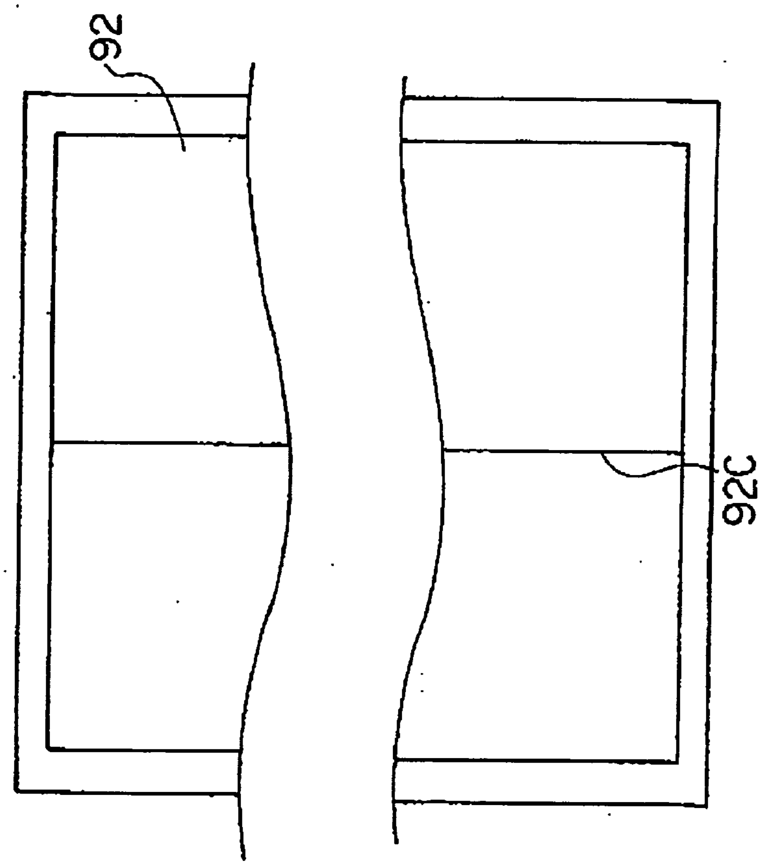


Fig.14(b)

Fig.15(a)

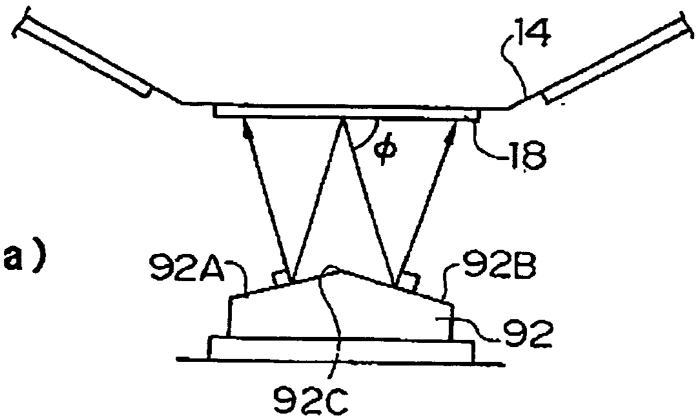


Fig.15(b)

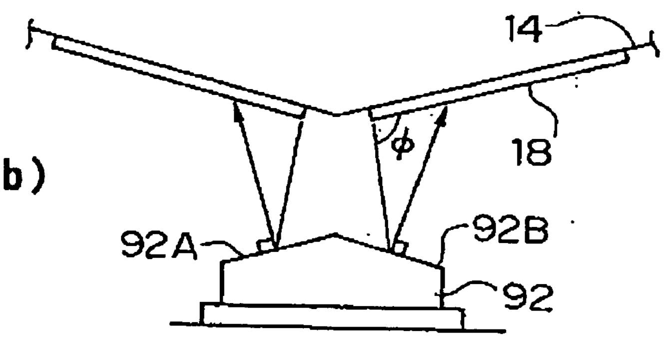


Fig.15(c)

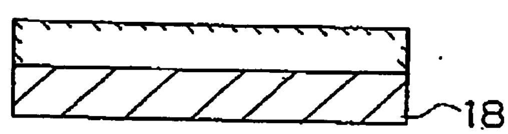
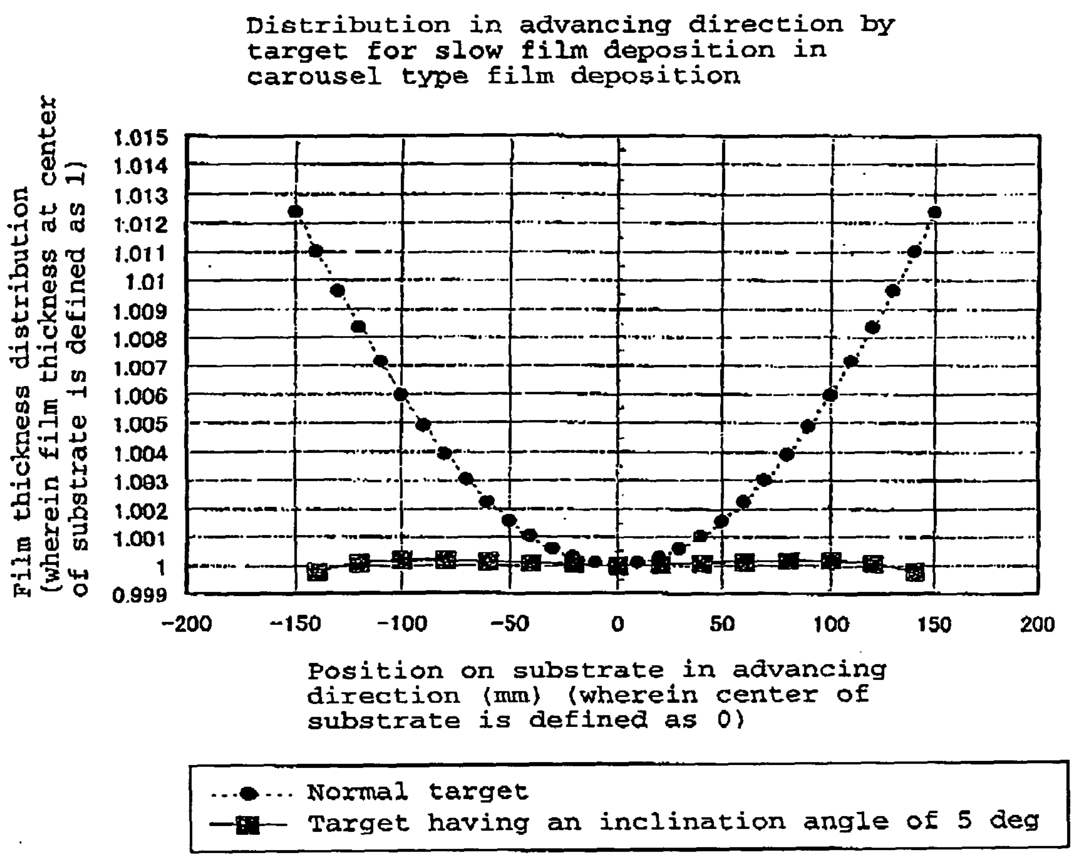


Fig.16


Distribution in advancing direction by target for slow film deposition in carousel type film deposition
Film thickness distribution (wherein film thickness at center of substrate is defined as 1)
1.015
1.014
1.013
1.012
1.011
1.01
1.009
1.008
1.007
1.006
1.005
1.004
1.003
1.002
1.001
1
0.999
-200
-150
-100
-50
0
50
100
150
200
Position on substrate in advancing direction (mm) (wherein center of substrate is defined as 0)
Normal target
Target having an inclination angle of 5 deg

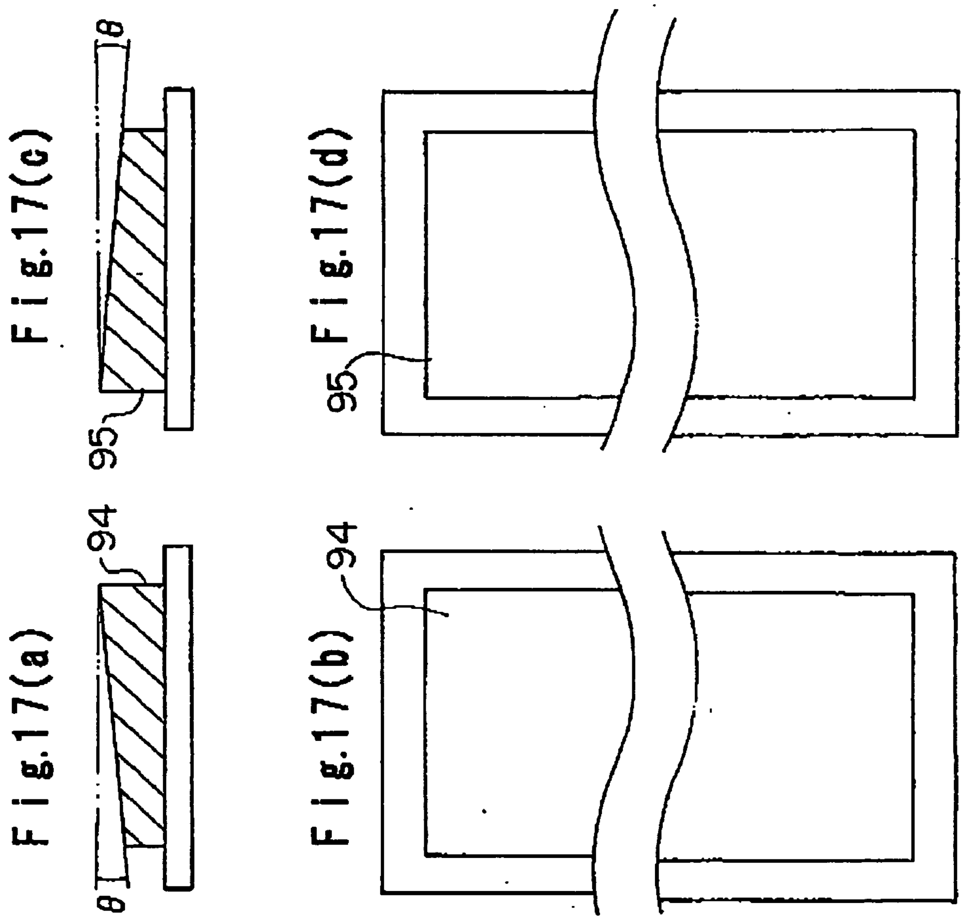


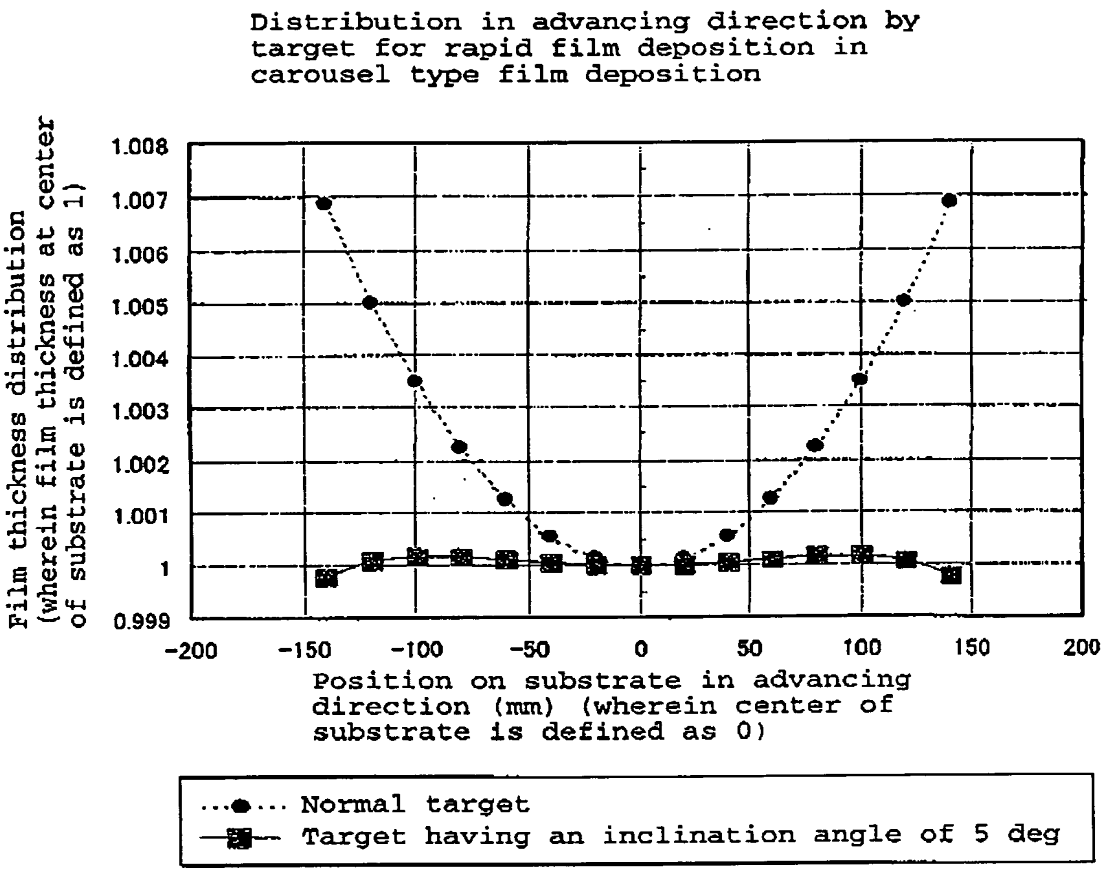
Fig.17(a)

Fig.17(b)

Fig.17(c)

Fig.17(d)

Fig.18


Distribution in advancing direction by target for rapid film deposition in carousel type film deposition
Film thickness distribution (wherein film thickness at center of substrate is defined as 1)
1.008
1.007
1.006
1.005
1.004
1.003
1.002
1.001
1
0.999
-200
-150
-100
-50
0
50
100
150
200
Position on substrate in advancing direction (mm) (wherein center of substrate is defined as 0)
Normal target
Target having an inclination angle of 5 deg

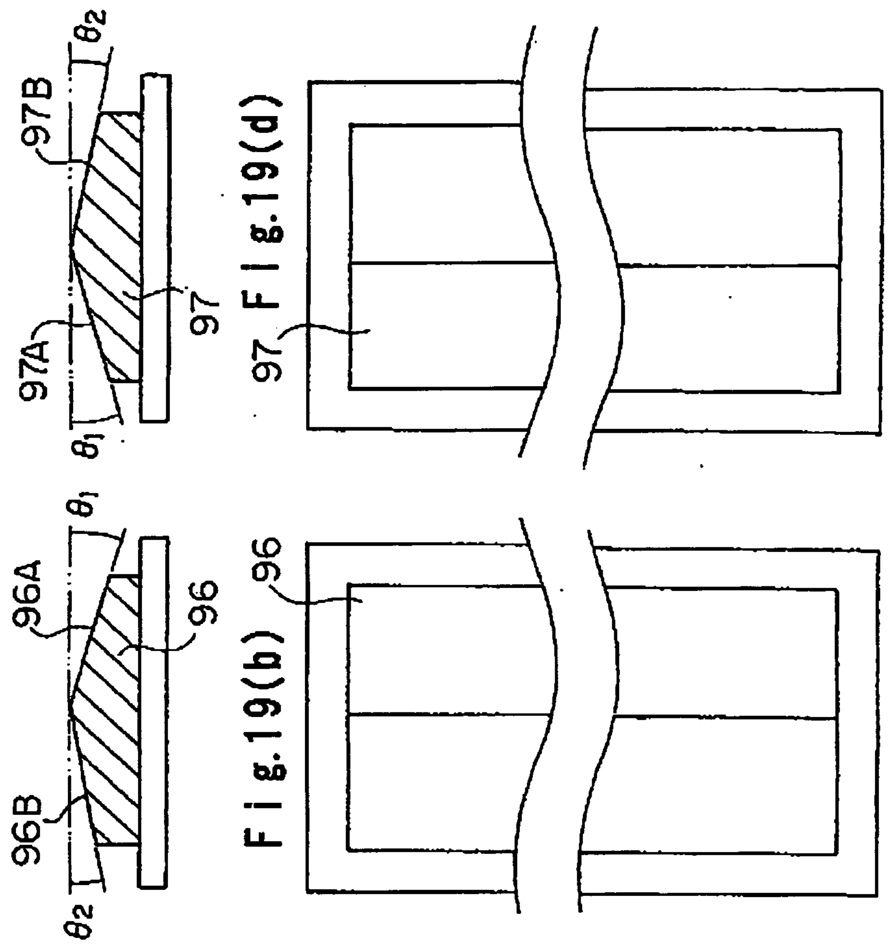


Fig.19(a)

Fig.19(b)

Fig.19(c)

Fig.19(d)

Fig.20

Change in transmittance of light having wavelength of 550 nm when TiO_2 (n=2.4) is deposited on glass substrate

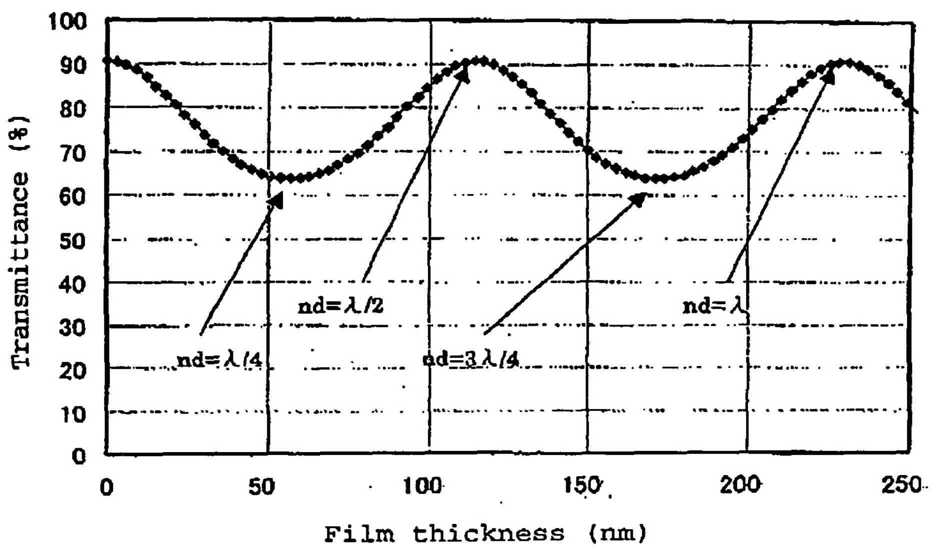


Fig.21

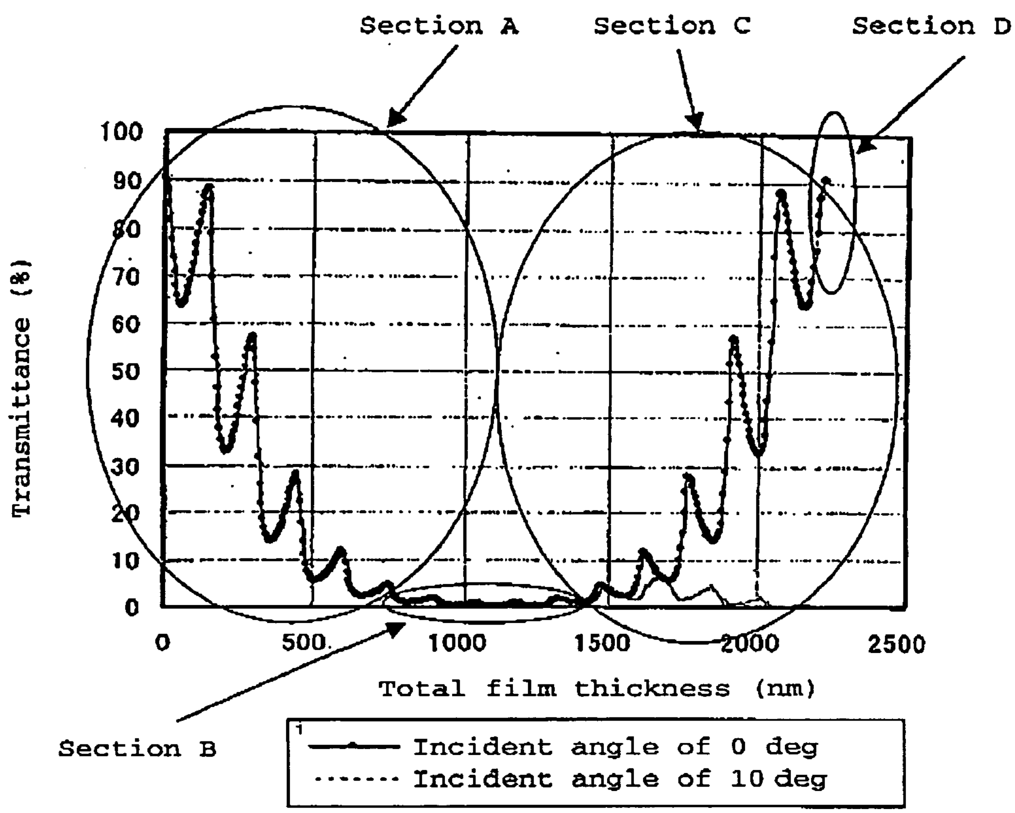

Section A
Section C
Section D
100
90
80
70
60
50
40
30
20
10
0
Transmittance (%)
0
500
1000
1500
2000
2500
Total film thickness (nm)
Section B
Incident angle of 0 deg
Incident angle of 10 deg

Fig.22

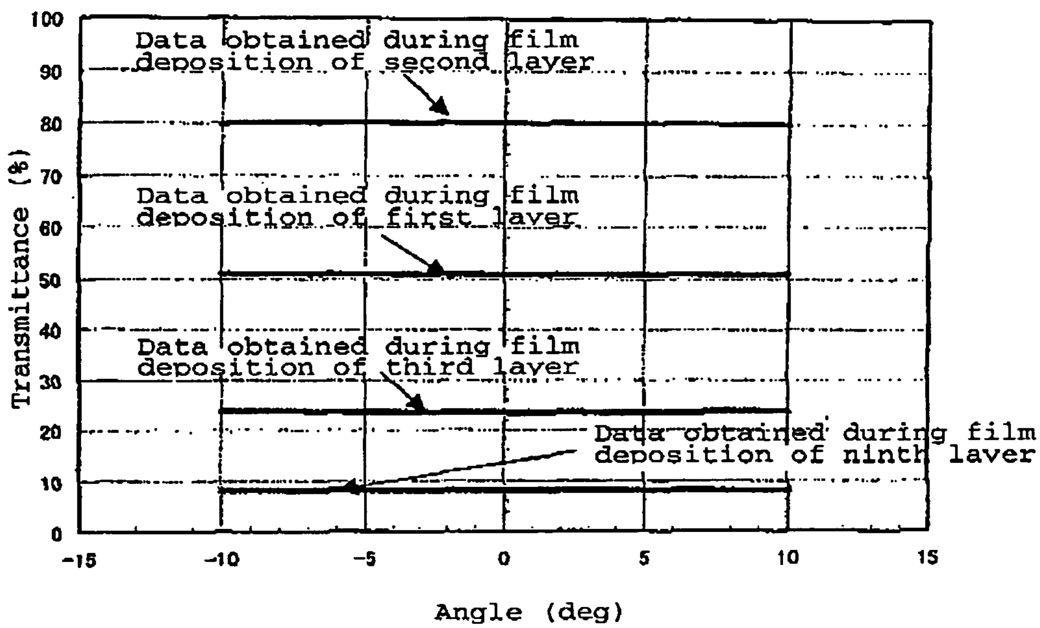

Data obtained during film deposition of second layer
Data obtained during film deposition of first layer
Data obtained during film deposition of third layer
Data obtained during film deposition of ninth layer
Transmittance (%)
Angle (deg)
100
90
80
70
60
50
40
30
20
10
0
-15
-10
-5
0
5
10
15

Fig.23

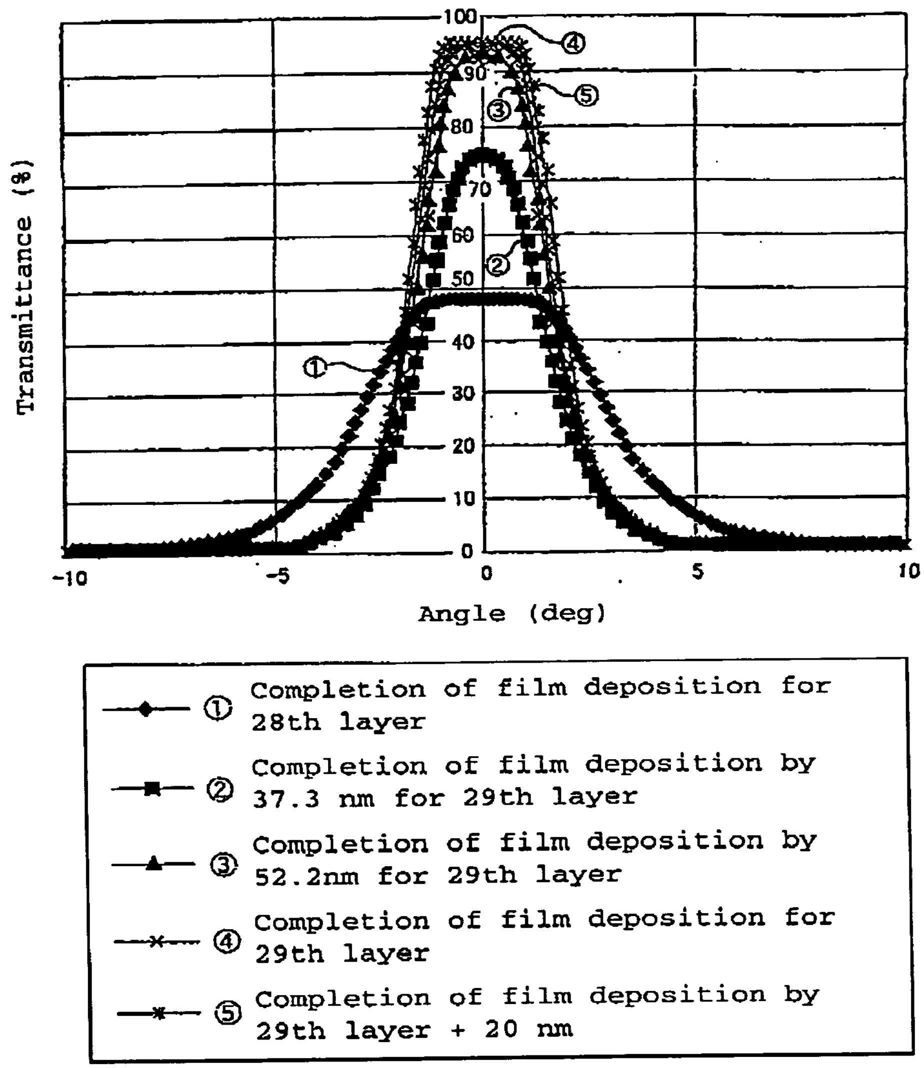

100
90
80
70
60
50
40
30
20
10
0
Transmittance (%)
-10
-5
0
5
10
Angle (deg)
①
②
③
④
⑤
① Completion of film deposition for 28th layer
② Completion of film deposition by 37.3 nm for 29th layer
③ Completion of film deposition by 52.2nm for 29th layer
④ Completion of film deposition for 29th layer
⑤ Completion of film deposition by 29th layer + 20 nm

Fig.24

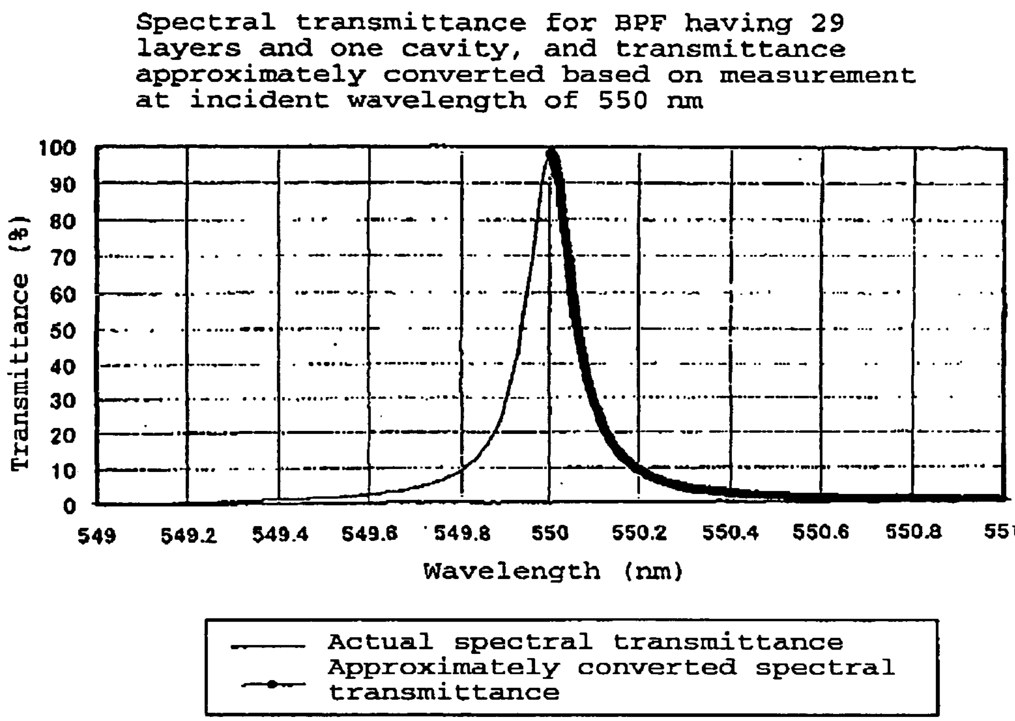

Spectral transmittance for BPF having 29 layers and one cavity, and transmittance approximately converted based on measurement at incident wavelength of 550 nm
Transmittance (%)
100
90
80
70
60
50
40
30
20
10
0
549
549.2
549.4
549.6
549.8
550
550.2
550.4
550.6
550.8
551
Wavelength (nm)
Actual spectral transmittance
Approximately converted spectral transmittance

Fig.25

Angular dependency of transmittance for BPF having 29 layers and one cavity

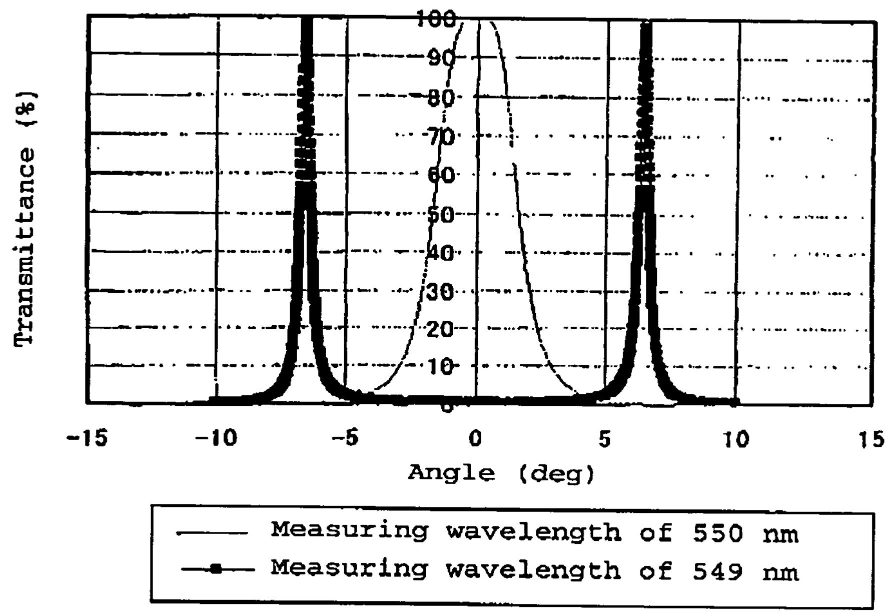


Fig.26

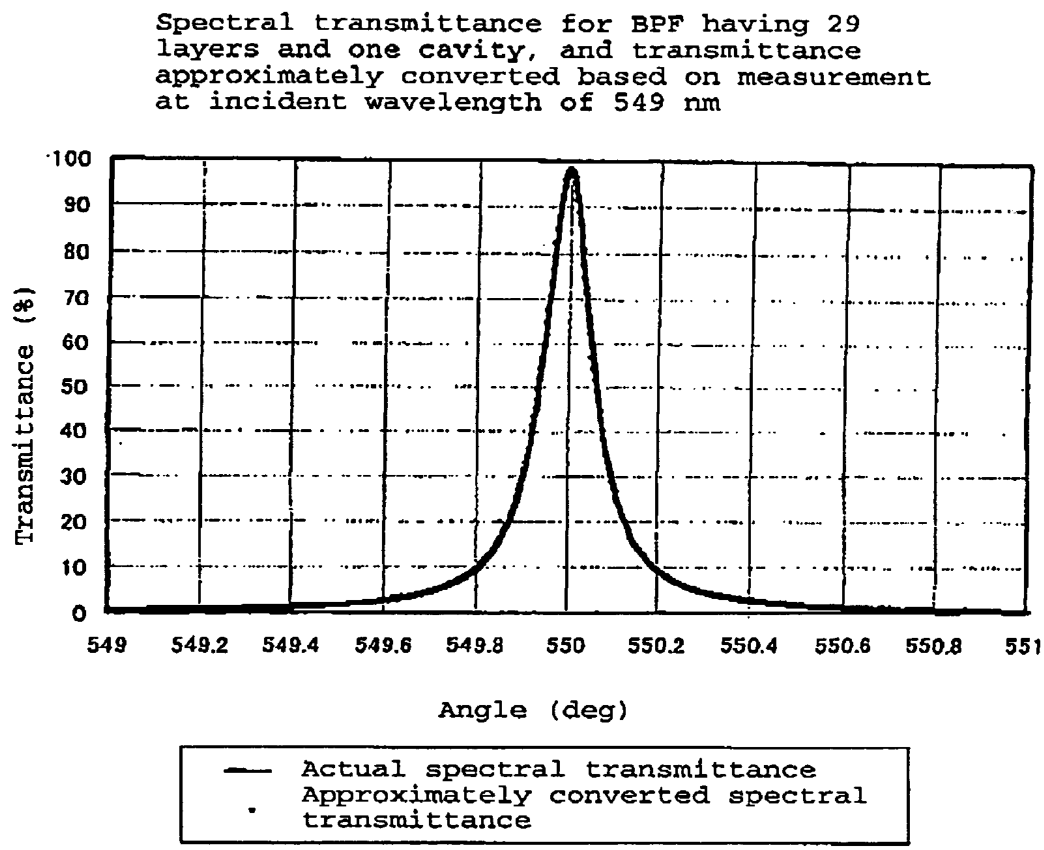

Spectral transmittance for BPF having 29 layers and one cavity, and transmittance approximately converted based on measurement at incident wavelength of 549 nm
Transmittance (%)
100
90
80
70
60
50
40
30
20
10
0
549
549.2
549.4
549.6
549.8
550
550.2
550.4
550.6
550.8
551
Angle (deg)
Actual spectral transmittance
Approximately converted spectral transmittance

Fig.27

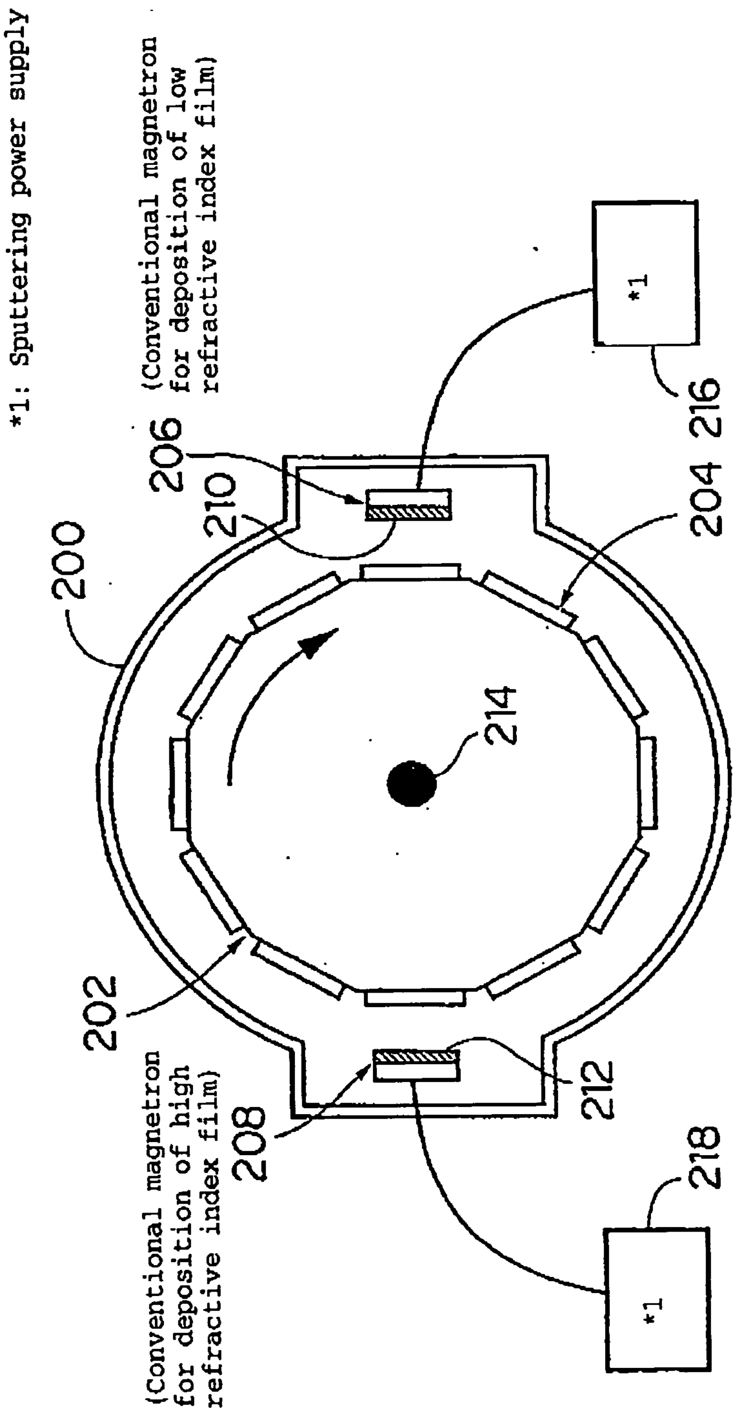

*1: Sputtering power supply
(Conventional magnetron for deposition of low refractive index film)
(Conventional magnetron for deposition of high refractive index film)
200
202
204
206
208
210
212
214
216
218
*1
*1

Fig.28

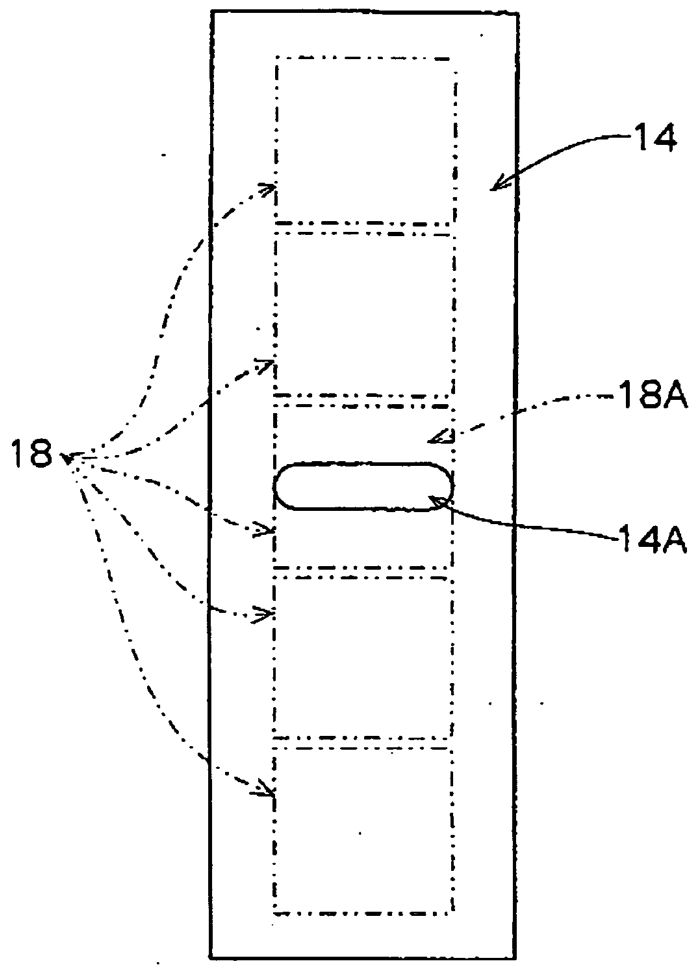


Fig.29

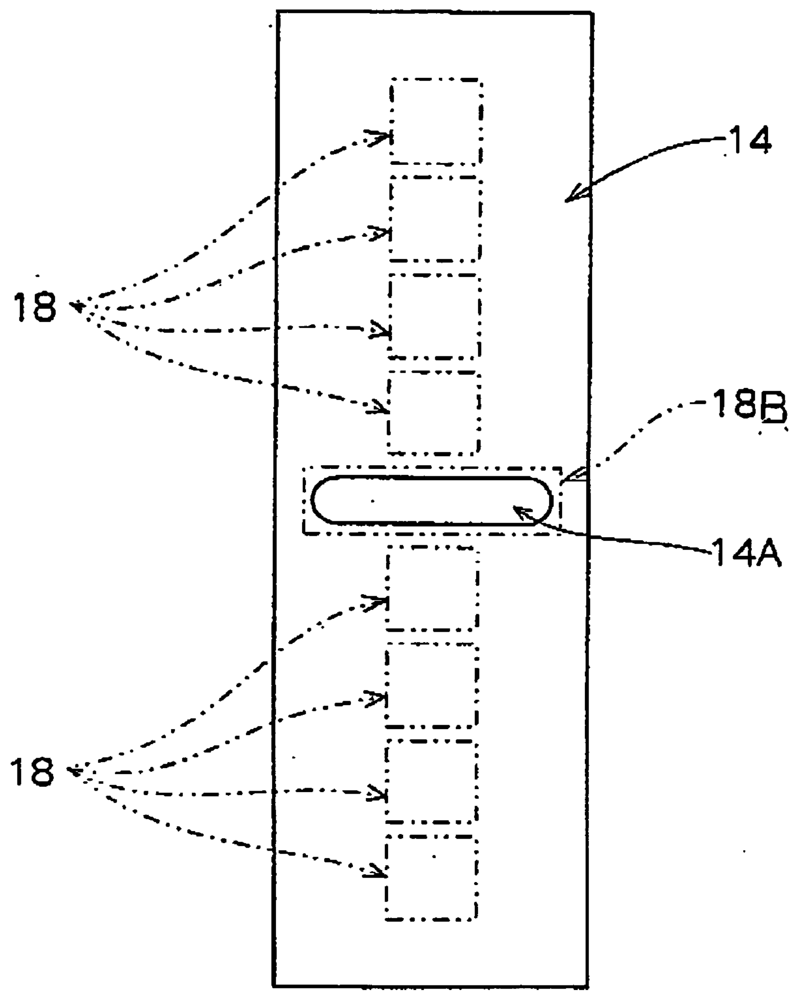


Fig.30

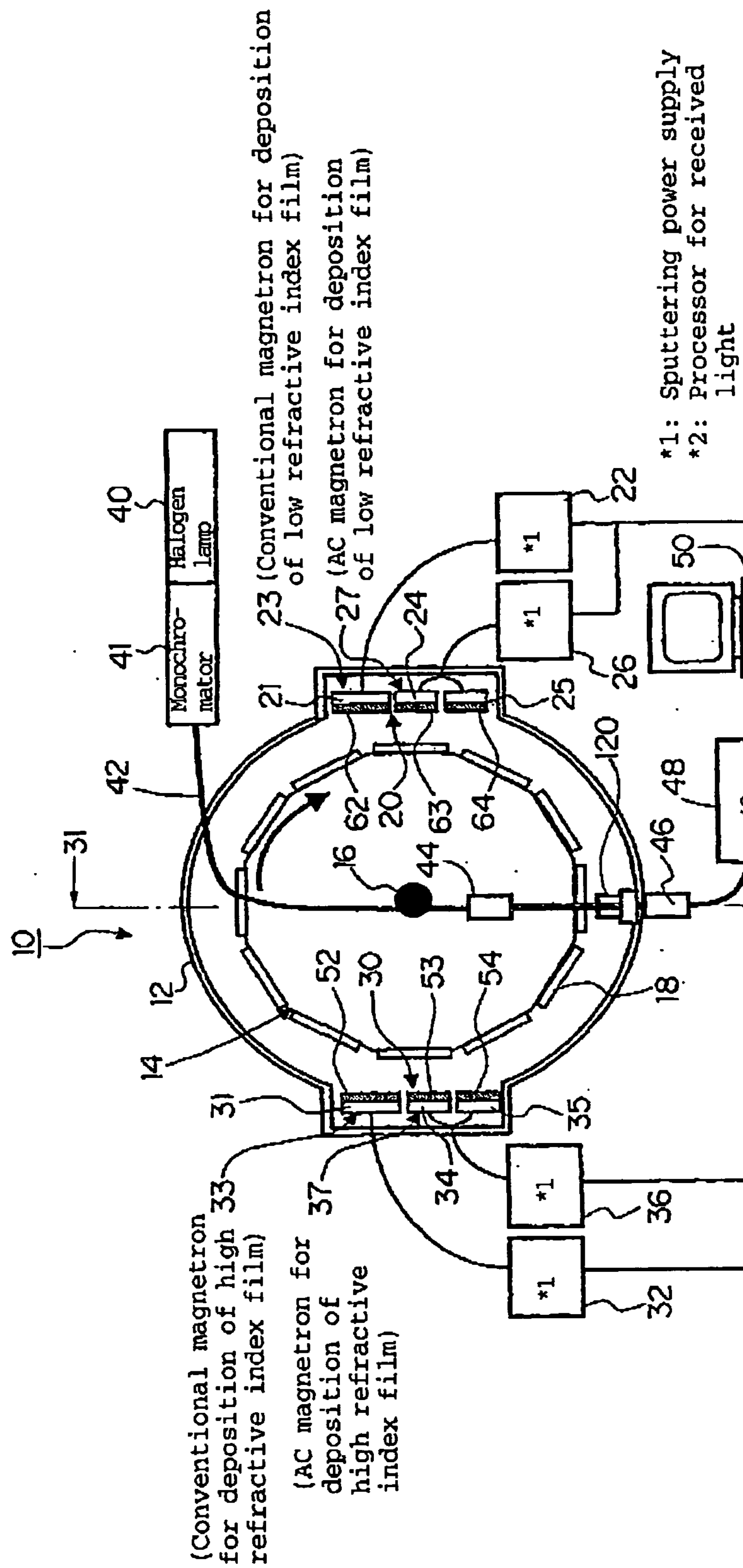

10
12
14
16
18
20
21
22
23 (Conventional magnetron for deposition of low refractive index film)
24
25
26
27 (AC magnetron for deposition of low refractive index film)
30
31
32
33 (Conventional magnetron for deposition of high refractive index film)
34
35
36
37 (AC magnetron for deposition of high refractive index film)
40
Halogen lamp
41
Monochro-mator
42
44
46
48
50
CPU
52
53
54
62
63
64
120
*1
*2
*1: Sputtering power supply
*2: Processor for received light

Fig.31

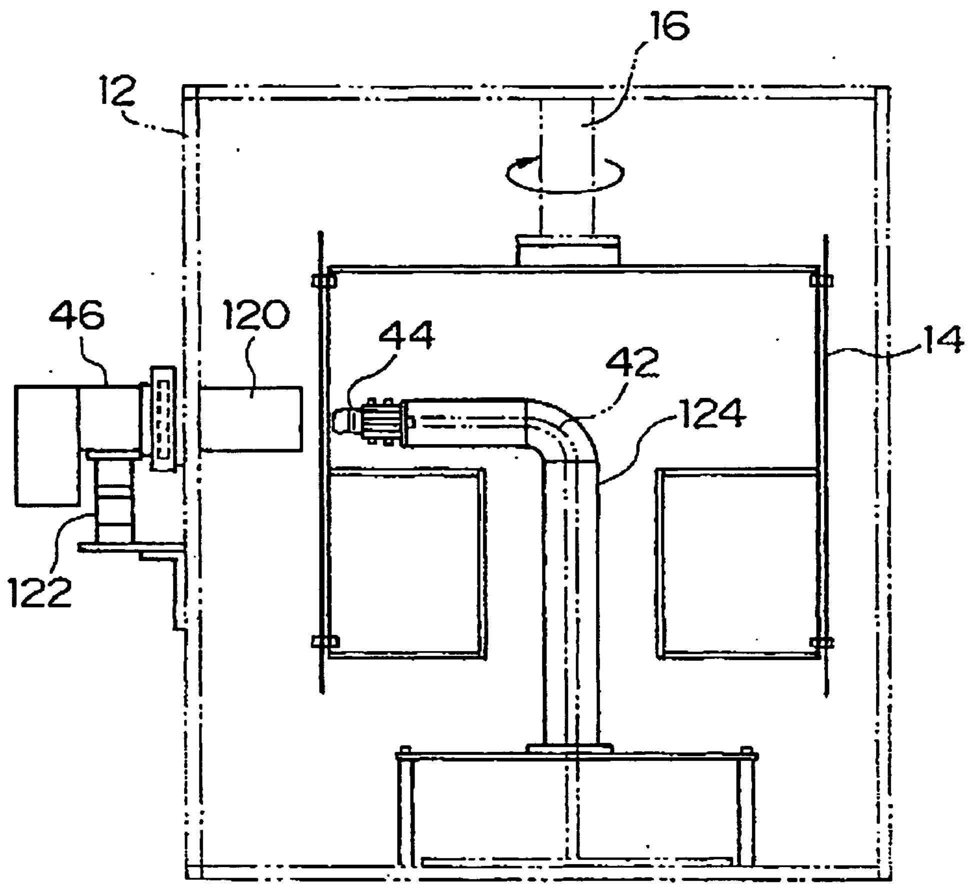


Fig.32

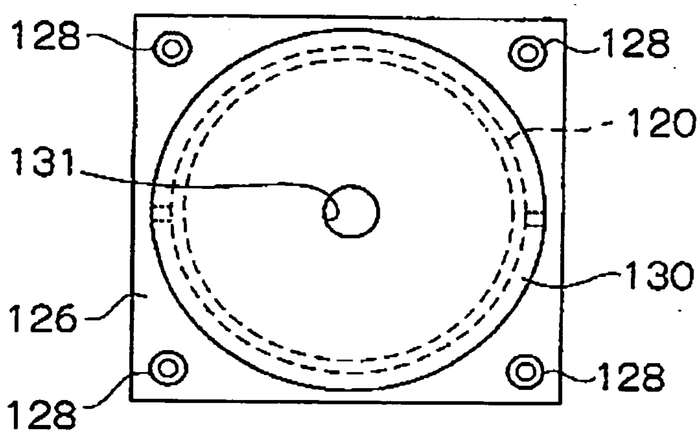


Fig.33

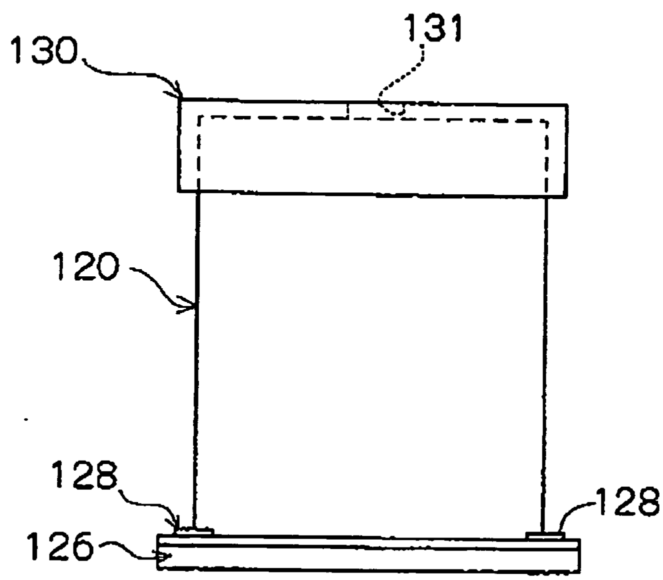


Fig.34

Example of film structure and film deposition method

Film deposition method	Kind of film	Number of film layer	Total film thickness (target)	Required precision of film thickness	Substrate holder Number of revolution (rpm)	Application
AC (rapid deposition) method	Antireflective film	1 to 4 layers (single side)	0.1 to 0.3 μm	1 to 5% or less	8 to 60 rpm	Various kinds of cameras Displays etc.
	Infrared reflective film Ultraviolet reflective film Ultraviolet/infrared reflective film Visual light reflective film Polarized separating film	15 to 50 layers	1.5 to 4.0 μm	1% or less		Lighting equipment Projectors Various kinds of cameras Displays etc.
Method wherein AC (rapid deposition) and DC (slow deposition) are combined	Band pass filter	100 to 200 layers	25 to 35 μm	0.01% or less	4 to 20 rpm	For WDM communi-cation
	Gain flattening target	30 to 40 layers	20 to 25 μm	0.01% or less		

Fig.35

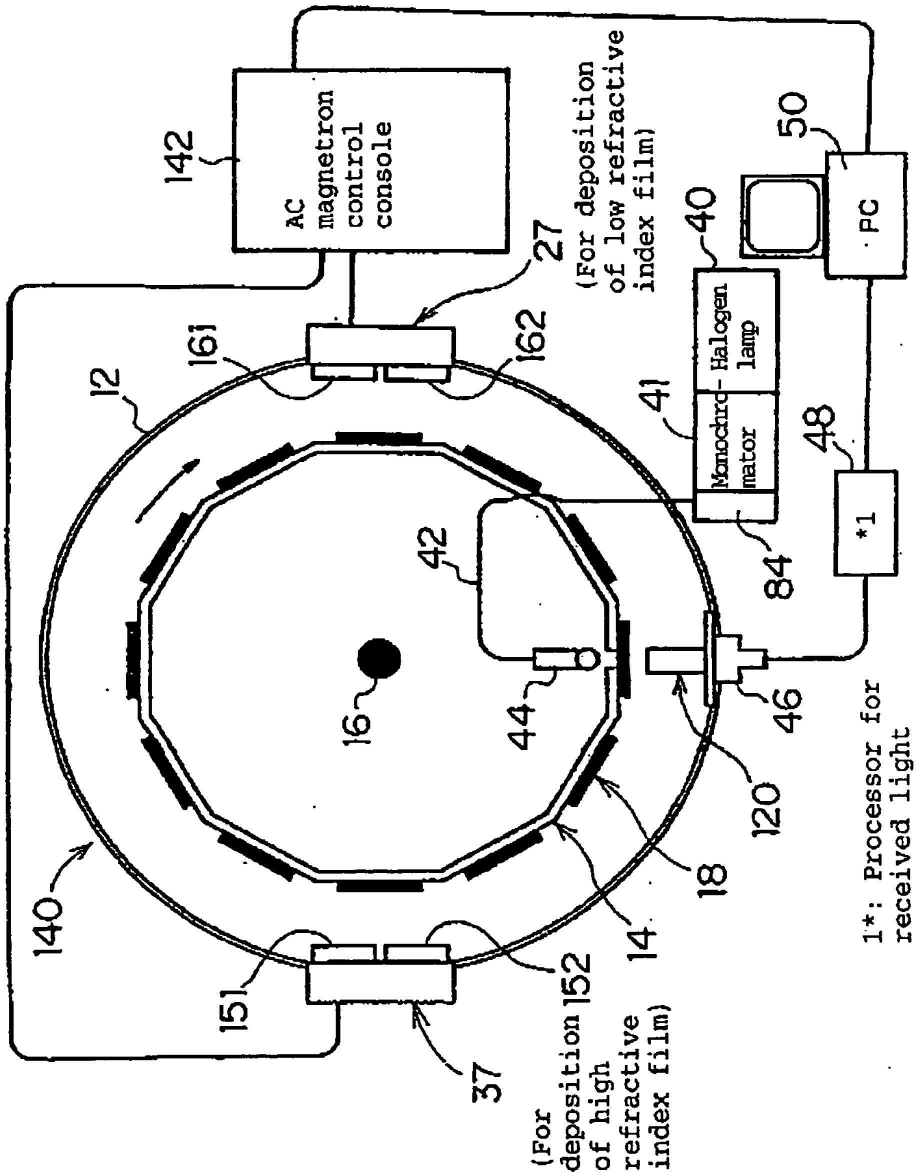

142
AC magnetron control console
27
(For deposition of low refractive index film)
40
Halogen lamp
41
Monochromator
50
PC
48
*1
84
161
162
12
42
44
46
16
120
18
14
140
151
152
37
(For deposition of high refractive index film)
1*: Processor for received light

Fig.36

Evaluation result for film property

	AC sputtering 10 layers 2.0 μm	DC sputtering 26 layers 3.0 μm	Product formed by vapor deposition 34 layers 4 μm
Film deposition rate (SiO_2)	42 nm·m/min	11 nm·m/min	-
Film deposition rate (Ta_2O_5)	52 nm·m/min	6 nm·m/min	
Film stress (SiO_2)	-218 MPa	-67 MPa	-
Film stress (Ta_2O_5)	-78 MPa	-217 MPa	
Refractive index (SiO_2)	1.472 at 550 nm	1.460 at 550 nm	-
Refractive index (Ta_2O_5)	2.17 at 550 nm	2.10 at 550 nm	
Extinction coefficient (SiO_2)	$< 10^{-4}$	$< 10^{-4}$	-
Extinction coefficient (Ta_2O_5)	$< 10^{-4}$	$< 10^{-4}$	
Haze value	0.0%	0.3%	0.3%
Smoothness (Ra)	0.32 nm	0.30 nm	2.22 nm
Wavelength shift (60°C, 90%RH, 120 h)	< 1 nm	< 1 nm	Less than 2 nm

(With respect to film deposition rate, film stress, refractive index and extinction coefficient, result for single film of 500 nm)

Fig.37

Film property required for multilayer optical film

	Targeted value
Film stress (SiO_2) (Ta_2O_5)	Within range of ±300 MPa
Refractive index (SiO_2)	1.45 or more and 1.48 or less
Refractive index (Ta_2O_5)	2.15 or more and 2.25 or less
Extinction coefficient (SiO_2)	$< 10^{-4}$
Extinction coefficient (Ta_2O_5)	$< 10^{-4}$
Haze value	< 0.1%
Smoothness (Ra)	< 1.0 nm
Wavelength shift (60°C, 90%RH, 120 h)	< 1 nm